

Population of Nuclei Via ${}^7\text{Li}$ -Induced Binary Reactions

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In recent years there has been increased interest in exploiting massive transfer (also called incomplete fusion) reactions for gamma-ray spectroscopic studies [1,2]. The reason for this interest is that massive transfer reactions offer access to states at relatively high angular momentum in neutron-rich heavy nuclei which are otherwise inaccessible by standard fusion-evaporation reactions involving stable beam-target combinations. Indeed, one may regard such massive transfer reactions as involving “quasi-radioactive” beams of high intensity. For instance, there is a significant probability of a ${}^9\text{Be}$ beam nucleus breaking up with the emission of a pre-equilibrium α particle while the remaining “ ${}^5\text{He}$ ” fragment fuses with a target nucleus. Similarly, a ${}^7\text{Li}$ nucleus can break up with a triton being captured while an α is emitted.

If such reactions are to be fully exploited for spectroscopy then a more quantitative understanding of the mechanism of energy and angular-momentum transfer is needed. For instance, it is generally recognized that cross-sections for specific nuclei formed via channels involving charged-particle emission are generally much higher (by one or two orders of magnitude) than the predictions of standard fusion-evaporation models. However, there are few quantitative measurements or calculations, especially for the reactions of interest to spectroscopists. We have made an effort to fill this gap in our understanding.

We have used the sum-rule model of Wilczyński et al., [3] to calculate the cross-sections of different transfer components in ${}^7\text{Li}$ -induced binary transfer reactions. We then use these results as input to a standard fusion-evaporation model. By assuming that the energy is shared between the captured and emitted fragments in proportion to their mass, and using the ground-state Q -values of each reaction channel, we are able to make predictions for the cross-sections of specific residual nuclei.

To test the model we used the results reported by Jungclaus et al., on the ${}^7\text{Li}+{}^{160}\text{Gd}$ reaction [2]. This reaction was successfully used to populate new high-angular-momentum states in several neutron-rich Dy nuclei. Cross-sections for different residual Dy nuclei were estimated from the measured γ -ray flux to the different ground-states, normalized to absolute X-ray yields. The Dy nuclei are formed by the massive transfer of “He”-like fragments (${}^{4,5,6}\text{He}$) from ${}^7\text{Li}$ to ${}^{160}\text{Gd}$. After taking into account the evaporation of nucleons, our calculations were able to reproduce the absolute cross-sections for the strongest residues to within a factor of two over a wide range of beam energy.

To test the model further, we compared its predictions to results from a recent experiment performed at the 88-Inch Cyclotron of the Lawrence Berkeley National Laboratory. The ${}^7\text{Li}+{}^{184}\text{W}$ reaction was used at beam energies in the

range 40 to 70 MeV. The beam was incident on a target comprising a 2.27 mg/cm^2 self-supporting foil of enriched ${}^{184}\text{W}$. Charged particles were detected with the STARS Si ΔE -E telescope system which consisted of two annular silicon-strip detectors covering an angular range of $\approx 20^\circ$ to 55° with respect to the beam direction. Gamma-rays were detected with the new LIBERACE (LIVERMORE BERKELEY ARRAY for COLLABORATIVE EXPERIMENTS) Ge-detector array which consists of six Compton-suppressed clover detectors situated in a close-packed configuration in the horizontal plane around the target chamber. Particle- γ and γ - γ coincidence events were recorded at 42, 49, and 55 MeV, while separate runs, with the Si detectors removed, recorded γ - γ events at 40 and 70 MeV.

The intention of the experiment was to perform γ -ray spectroscopy on poorly known neutron-rich Re and Os nuclei populated in transfer channels. This prohibited a quantitative measurement of relative cross-sections estimated from the γ -ray flux to the different ground states of these nuclei. However, there was good qualitative agreement with the calculations in terms of which of the Ir, Re, and Os nuclei were strongly populated at each of the beam energies. The particle information allowed a quantitative comparison with our calculations. We measured the ratio of the number of α -particles to the number of tritons, $I(\alpha/t)$, and the ratio of the number of tritons to the number of deuterons, $I(t/d)$, produced at 42, 49, and 55 MeV. The comparison to the calculation is shown in Fig. 1. We find a good quantitative agreement between the measured numbers of particles and the Wilczyński binary transfer model.

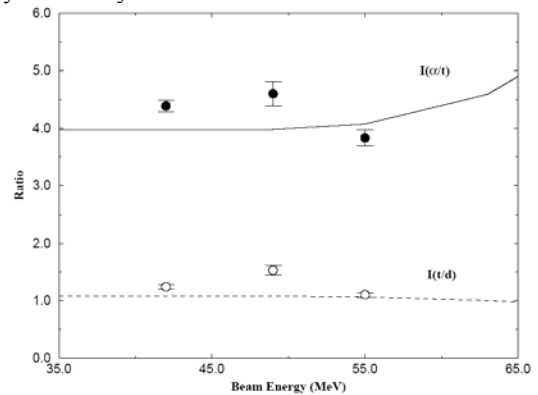


Fig. 1: Comparison of experimental and calculated values of $I(\alpha/t)$ and $I(t/d)$ as a function of beam energy.

REFERENCES

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